Multiplicity dependence of light flavor production in p-Pb collisions measured with ALICE at the LHC

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Outline

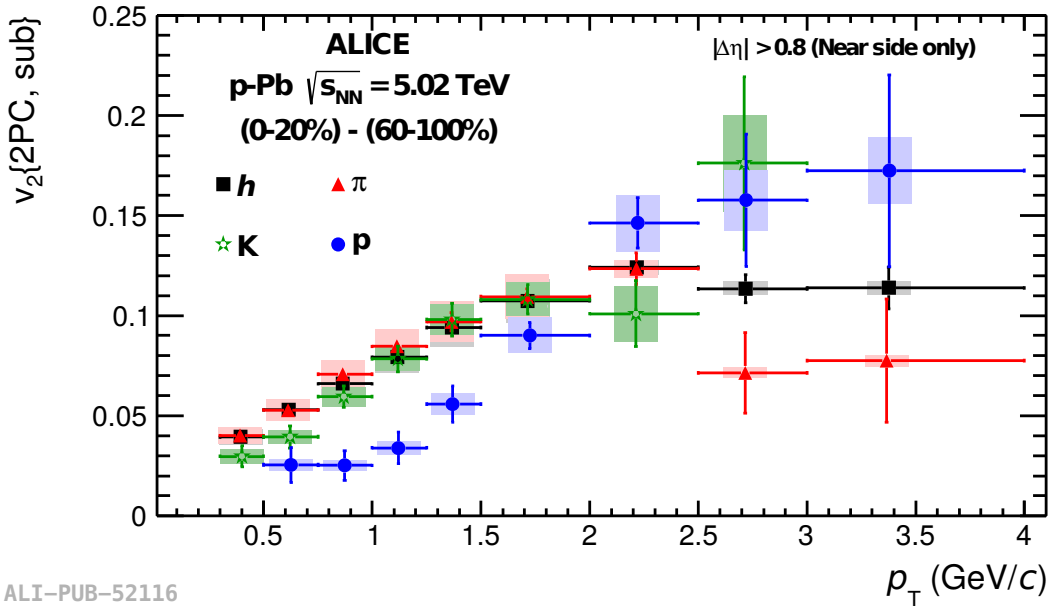
- Introduction
- Particle identification in ALICE
- Light flavor production at 5.02 ATeV in p-Pb collisions
  - Multiplicity dependence of pion, kaon and proton production
    - Blast wave analysis of particle spectra
  - Multiplicity dependence of kaon/pion and proton/pion particle ratios
  - Nuclear modification factor of pions, kaons and protons
- Summary

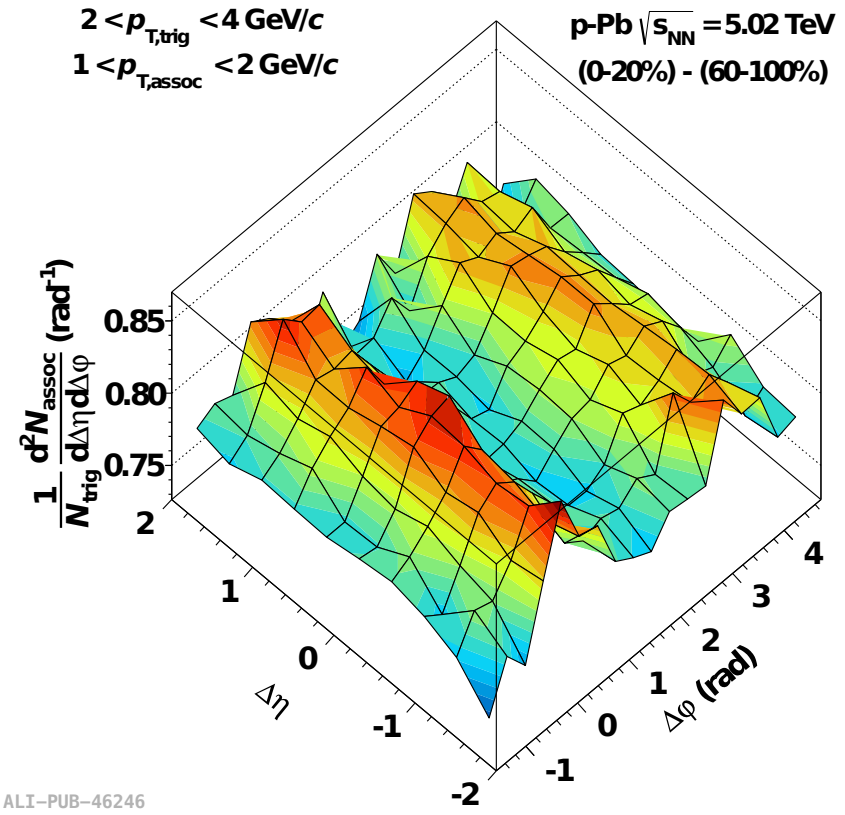
Introduction

- p-A collisions: control measurement (beside pp collisions) in order to better understand heavy ion collisions, i.e. disentangle initial- and final state effects
- At high p_T (final state effects)
  - **study parton energy loss** mechanisms in QGP
- At intermediate p_T (initial state effects)
  - obtain higher precision in the existing measurements (ITS, TPC, TOF)
  - **study Cold Nuclear Matter effects** (e.g. Cronin enhancement) and modification of particle ratios (p/pi and K/pi) by flow-like effects

Cold Nuclear Matter effects

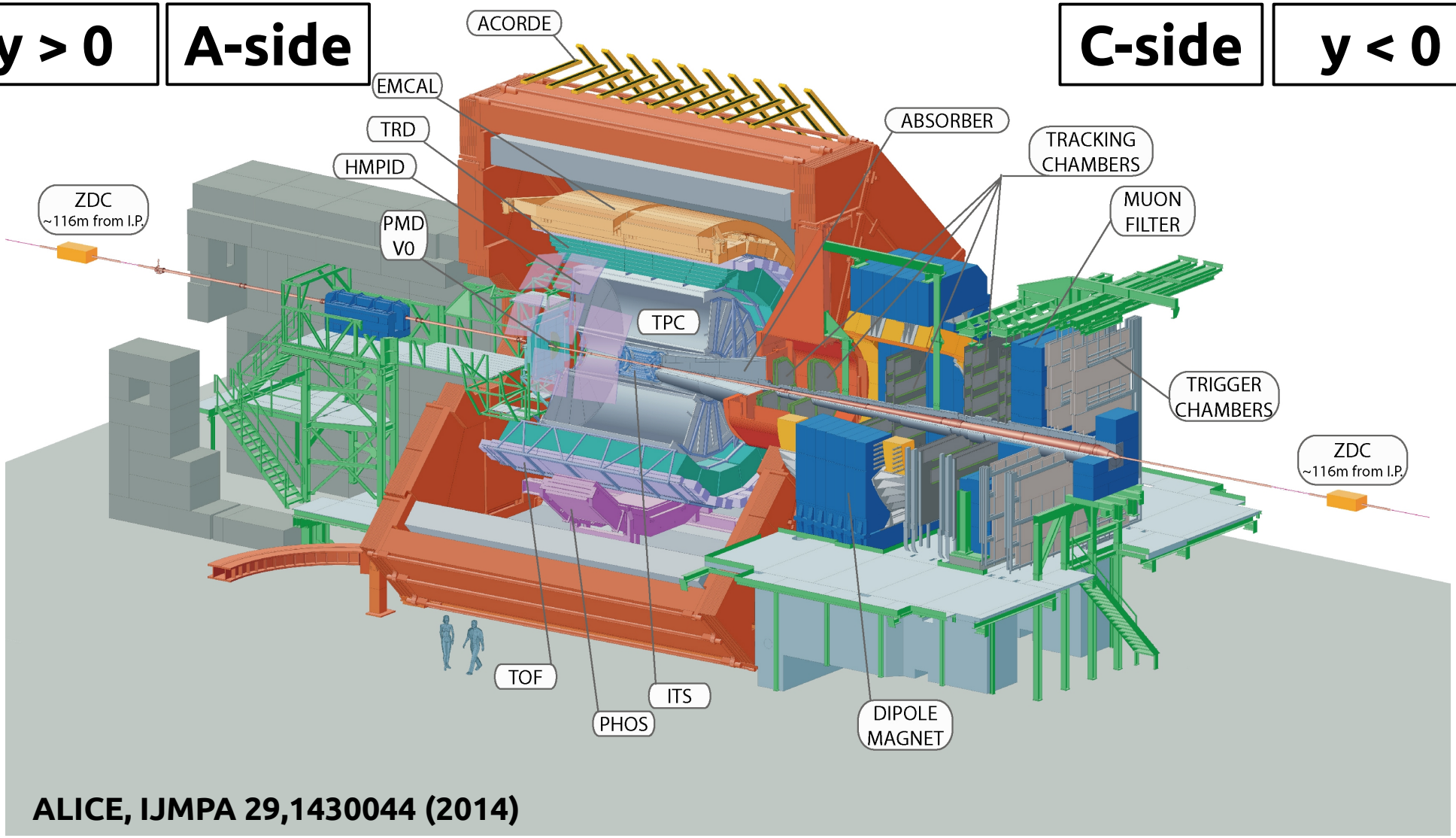
- **Double ridge structure**, long-range angular correlations **in p-Pb** collisions at **high multiplicity** (near- and away side)
- **Flow-like patterns** observed
- **Mass ordering** and crossing is qualitatively **similar** to observations in **A-A collisions**
  - at low p_T can be described by hydrodynamic models





ALICE, PLB 719 (2013) 29-41
ALICE, PLB 726 (2013) 164-177
ALICE, PLB 728 (2014) 25-38
CMS, PLB 718 (2013) 795

The ALICE apparatus



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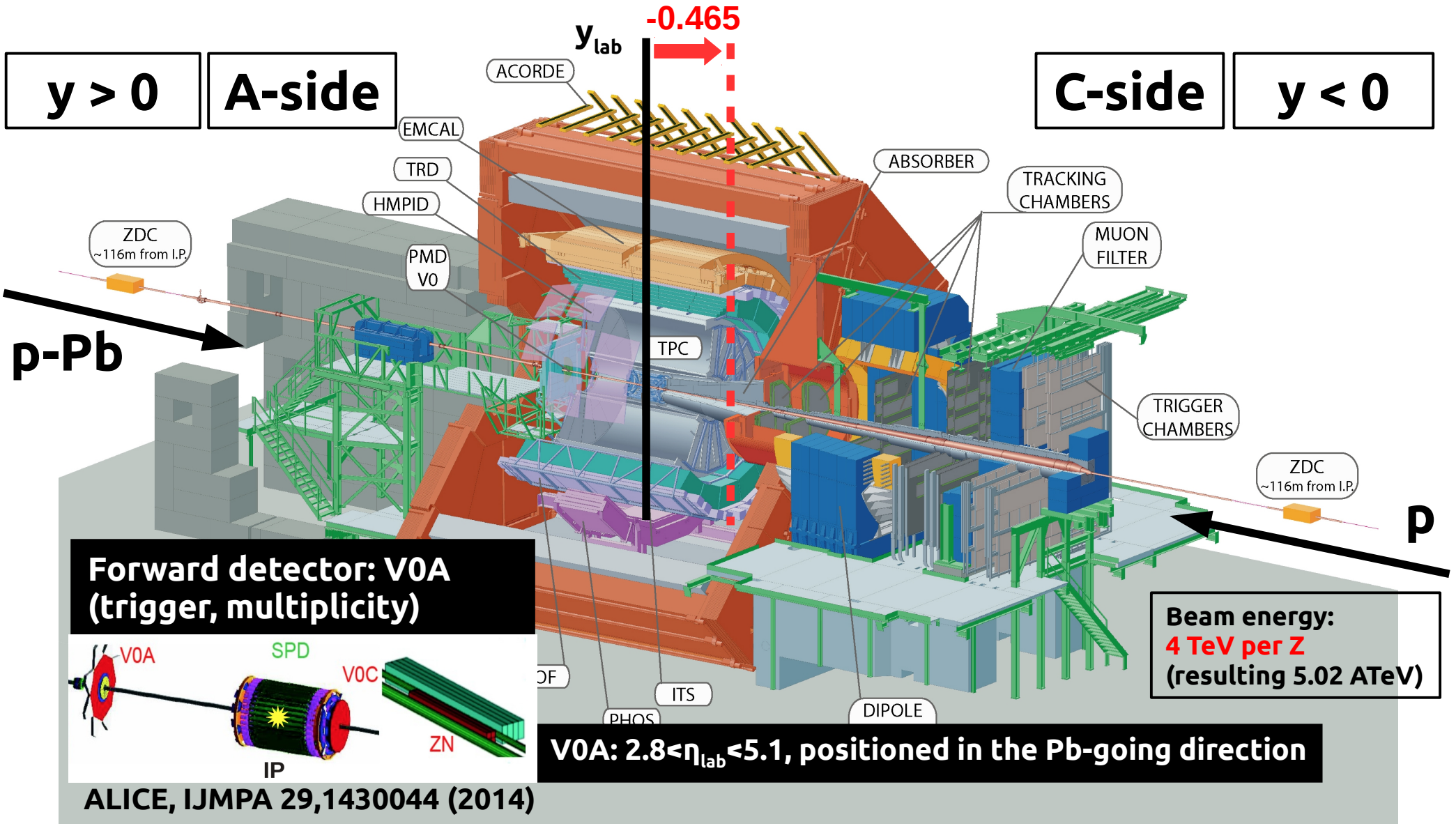
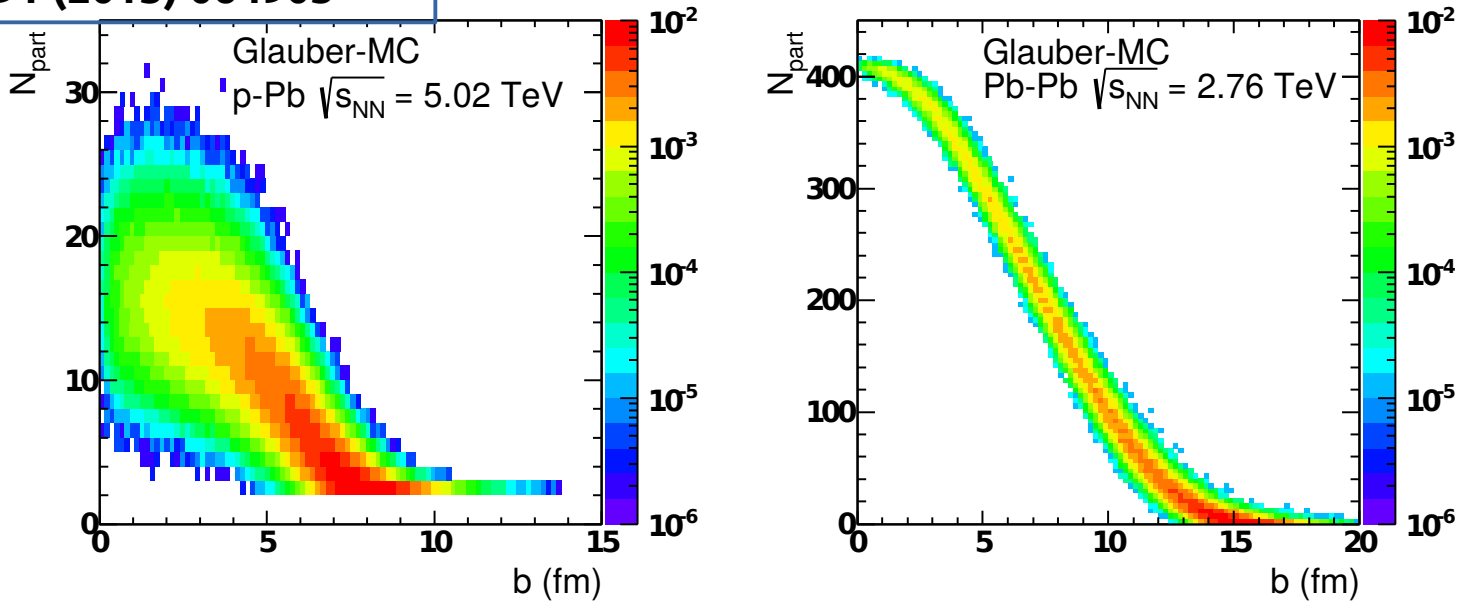
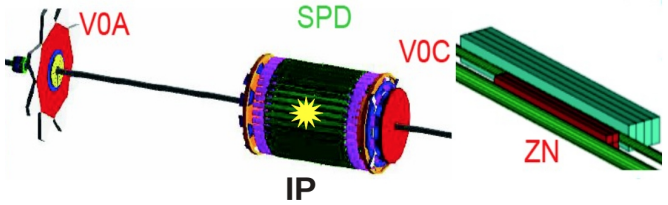


Multiplicity estimation: V0A

ALICE PRC 91 (2015) 064905

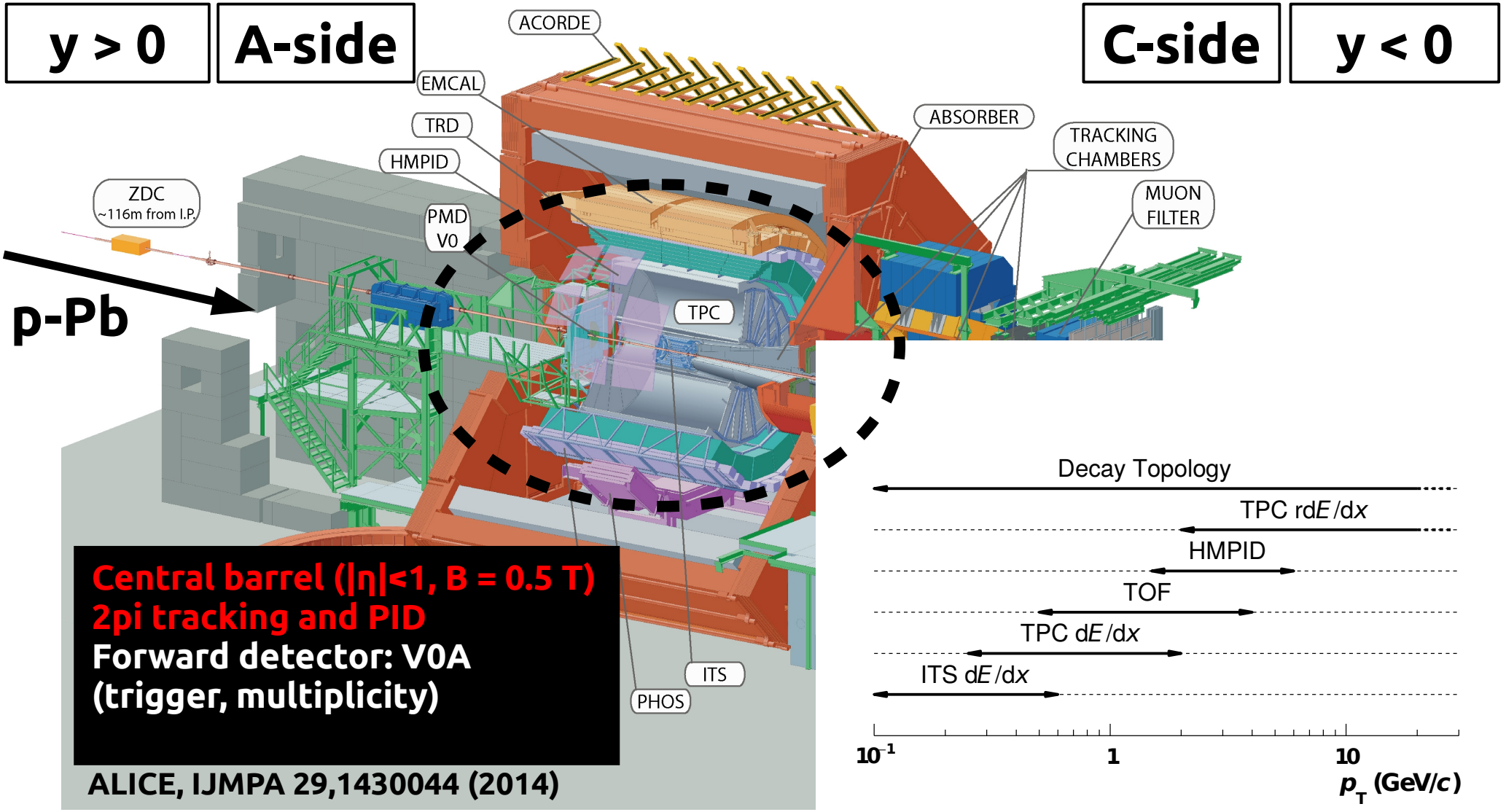


- For small systems there is a weak correlation between the *impact parameter (b)* and the *number of participants (N_{part})*
- For this reason particle production is studied in event multiplicity classes V0A estimator is used (as in the first ALICE publication on identified hadron production in p-Pb collisions)



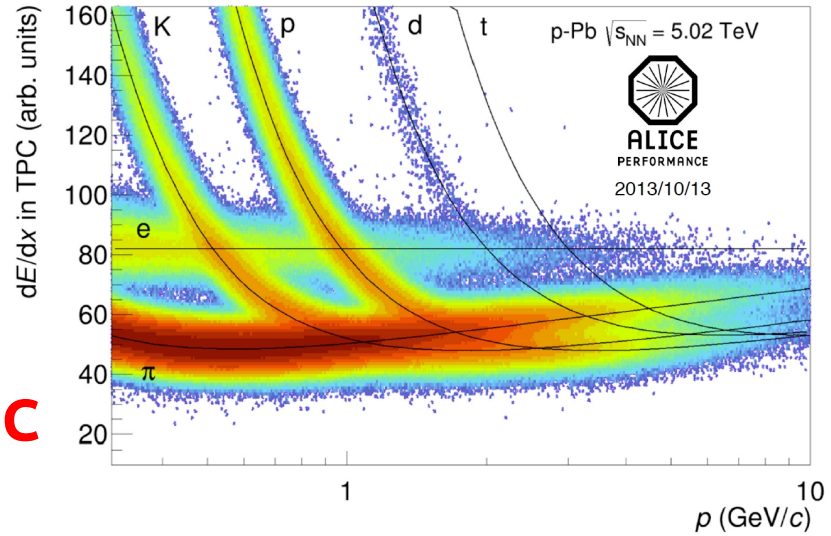
V0A detector: $2.8<\eta_{lab}<5.1$, positioned in the Pb-going direction

The ALICE apparatus



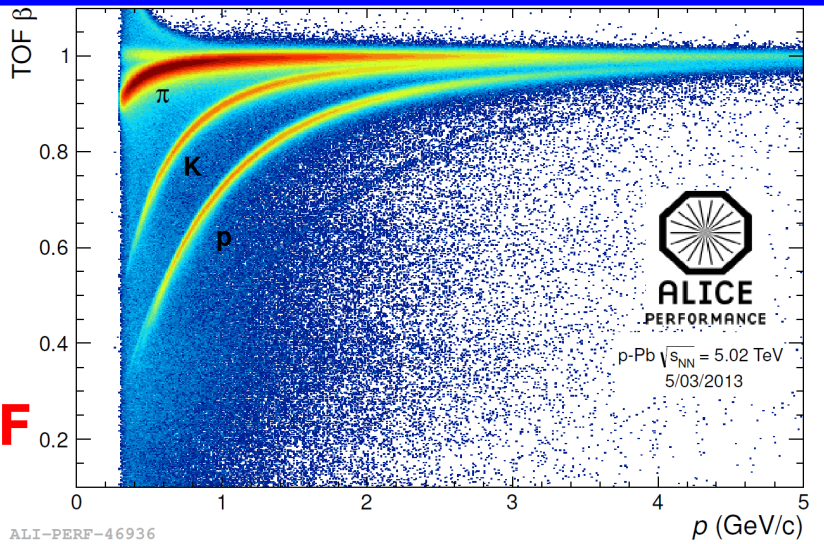
Particle Identification

- **Track-by-track ID (n-σ cut) in the $1/\beta^2$ region**
- **PID in the relativistic rise using statistical approaches**



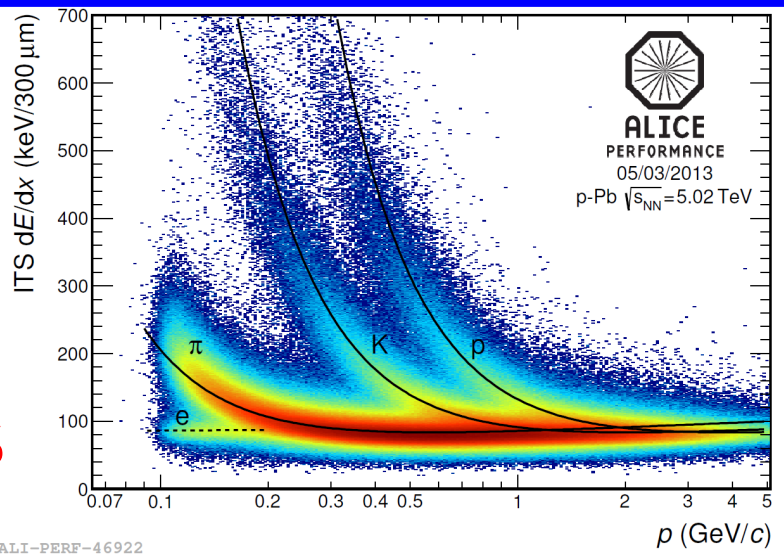
TPC

Dedicated to charged hadron Identification in the intermediate momentum region



TOF

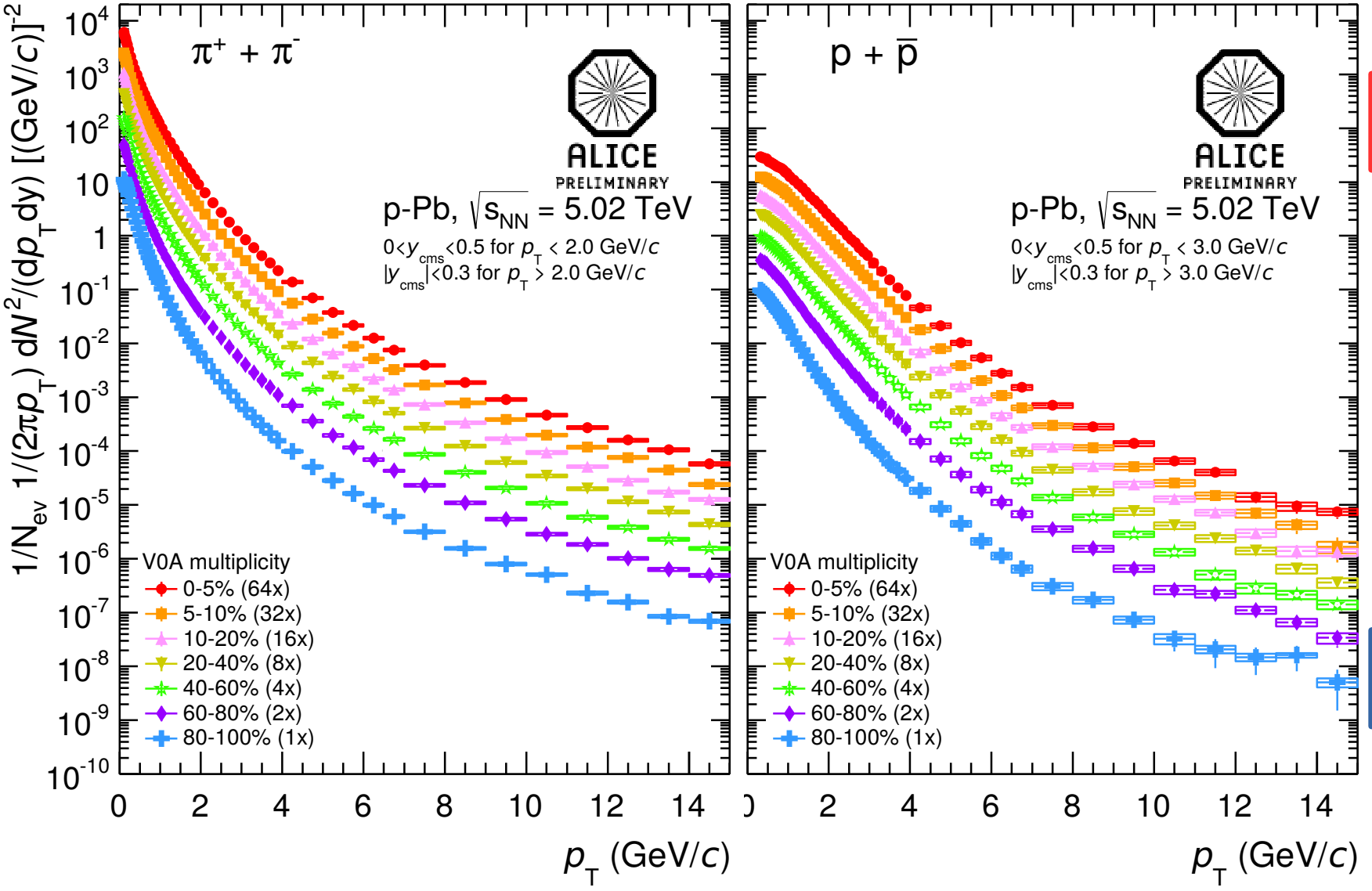
- **Tracking + standalone reconstruction: PID via d*E*/d*x* from SDD and SSD analog read-out**
- **Standalone tracking in the low-p_T region (down to 100MeV/*c*)**



ITS

Light flavor production at 5.02 ATeV in p-Pb collisions

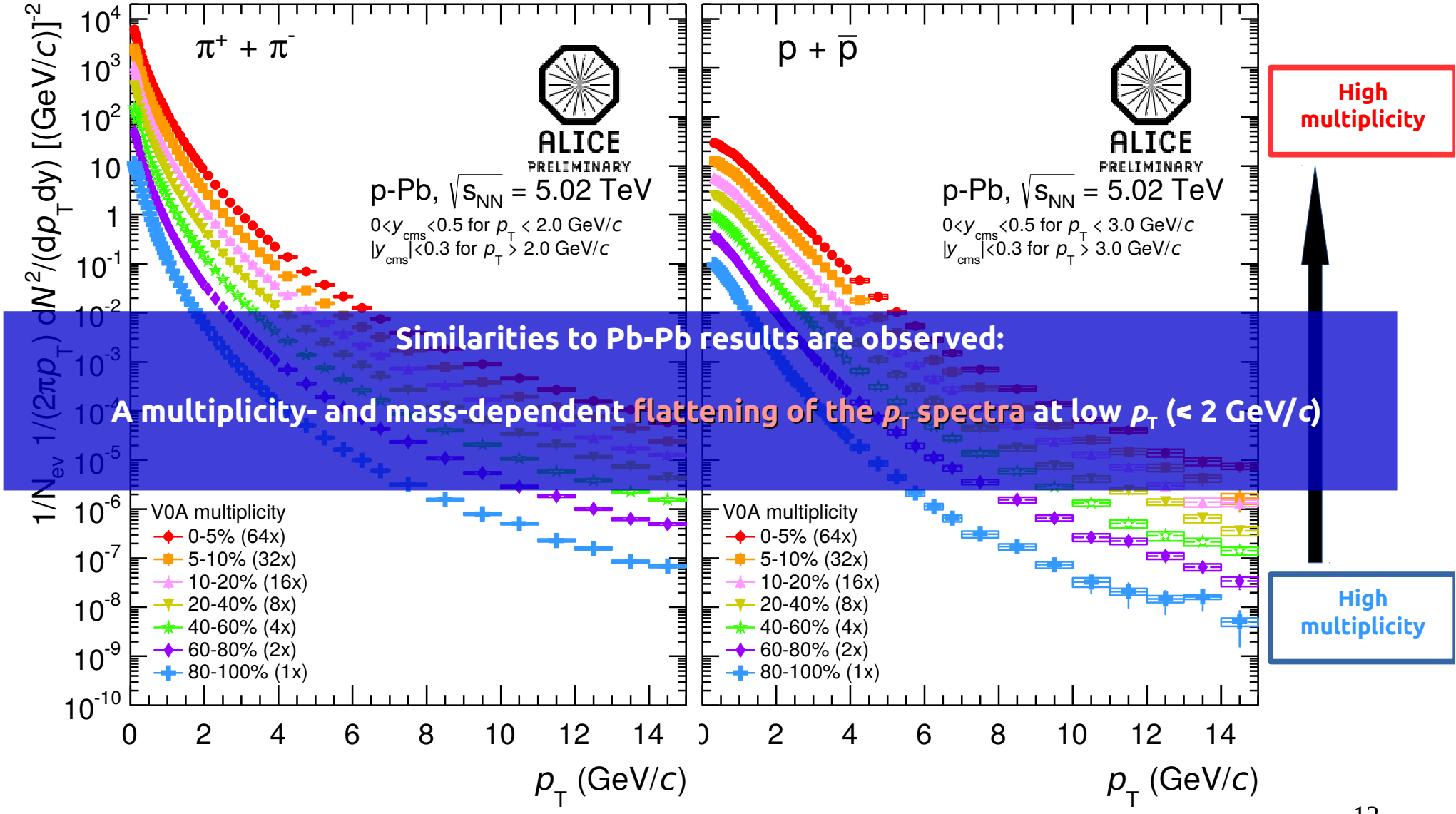
Multiplicity dependence of pi/K/p spectra



High multiplicity

High multiplicity

Multiplicity dependence of pi/K/p spectra

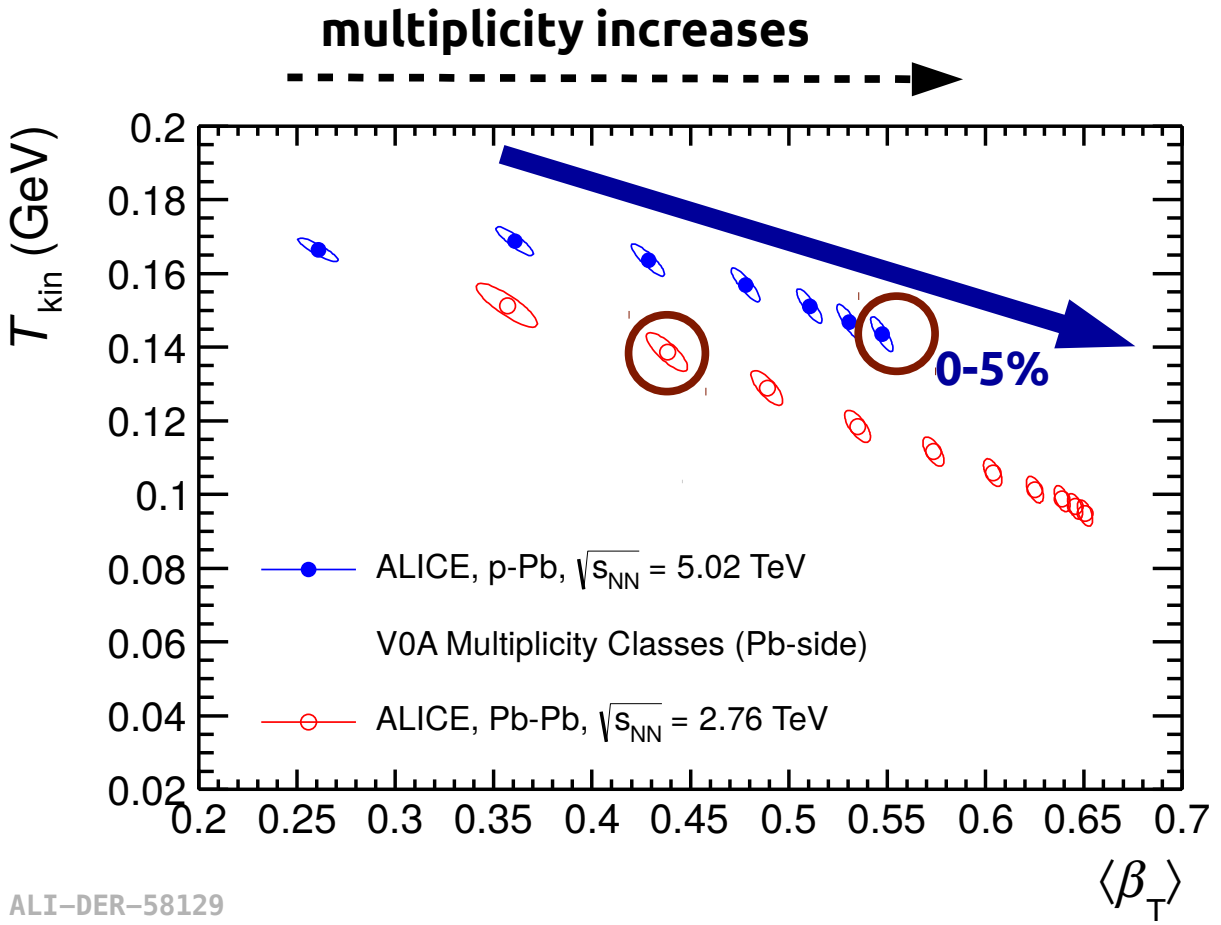


Similarities to Pb-Pb results are observed:

A multiplicity- and mass-dependent flattening of the p_T spectra at low p_T (< 2 GeV/c)

Blast wave fits to the spectra

The flattening and mass ordering of the p_T spectra can be studied by applying simultaneous Blast-Wave fits to pi, K, p, K^0_s and Λ p_T spectra in V0A multiplicity classes



- **Qualitatively similar behavior** observed **for p-Pb** and Pb-Pb collisions
- **Larger radial flow parameter** obtained **in p-Pb** than in Pb-Pb collisions at similar multiplicity
  - → consequence of selection bias of harder events?
  - → consequence of stronger radial gradients? (**Phys.Rev. C88 (2013) 4, 044915**)

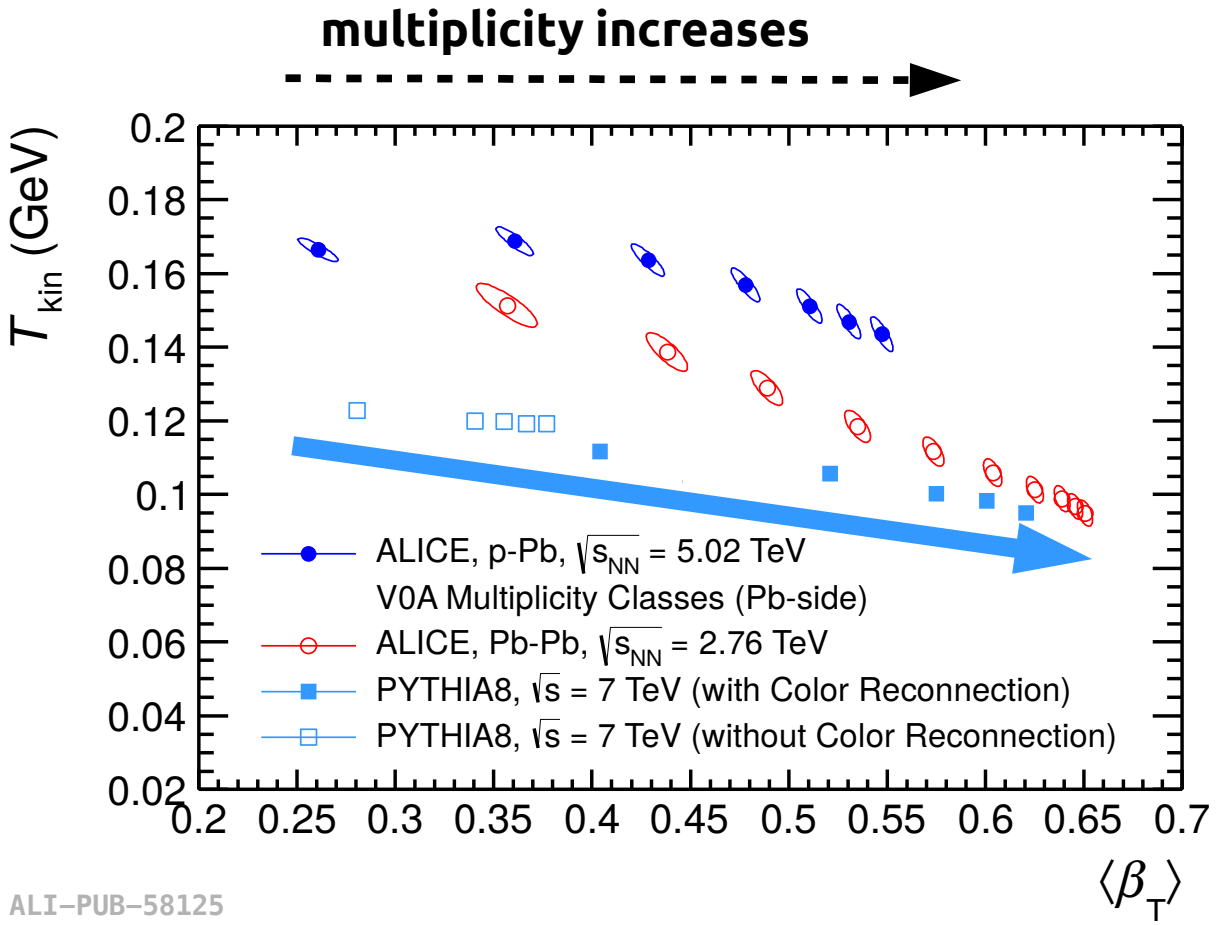
- In p-Pb data there is a presence of flow-like effects
- In Pb-Pb strong radial flow is observed **Phys. Rev. Lett. 109 (2012) 252301**

Blast wave fits to the spectra

The flattening and mass ordering of the p_T spectra can be studied by applying simultaneous Blast-Wave fits to pi, K, p, K^0_s and Λ p_T spectra in V0A multiplicity classes

- Simulated pp events (PYTHIA8, CR) without hydrodynamical expansion of the system show similar trend to those observed in p-Pb and Pb-Pb collisions

A. Ortiz *et al.* PRL 111 (2013) 4, 042001



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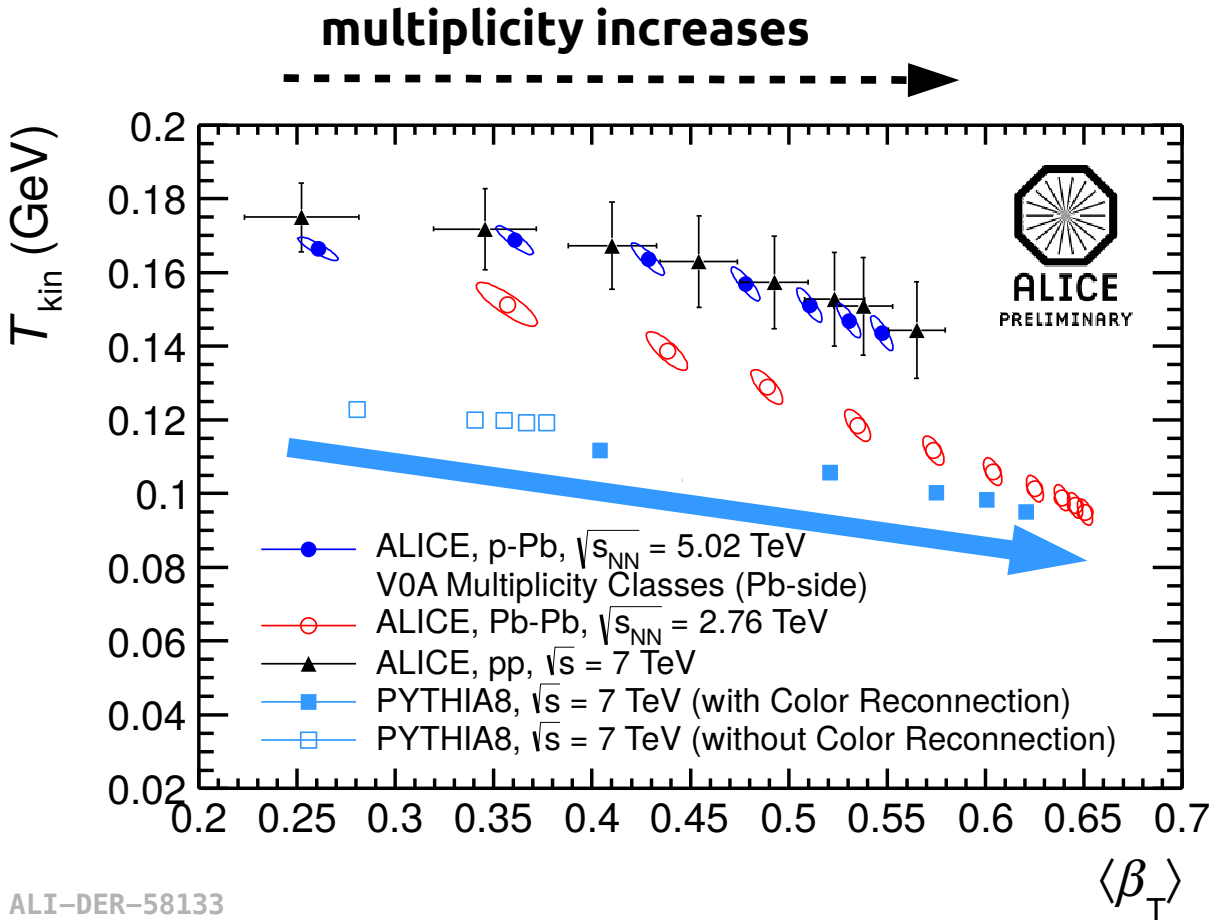

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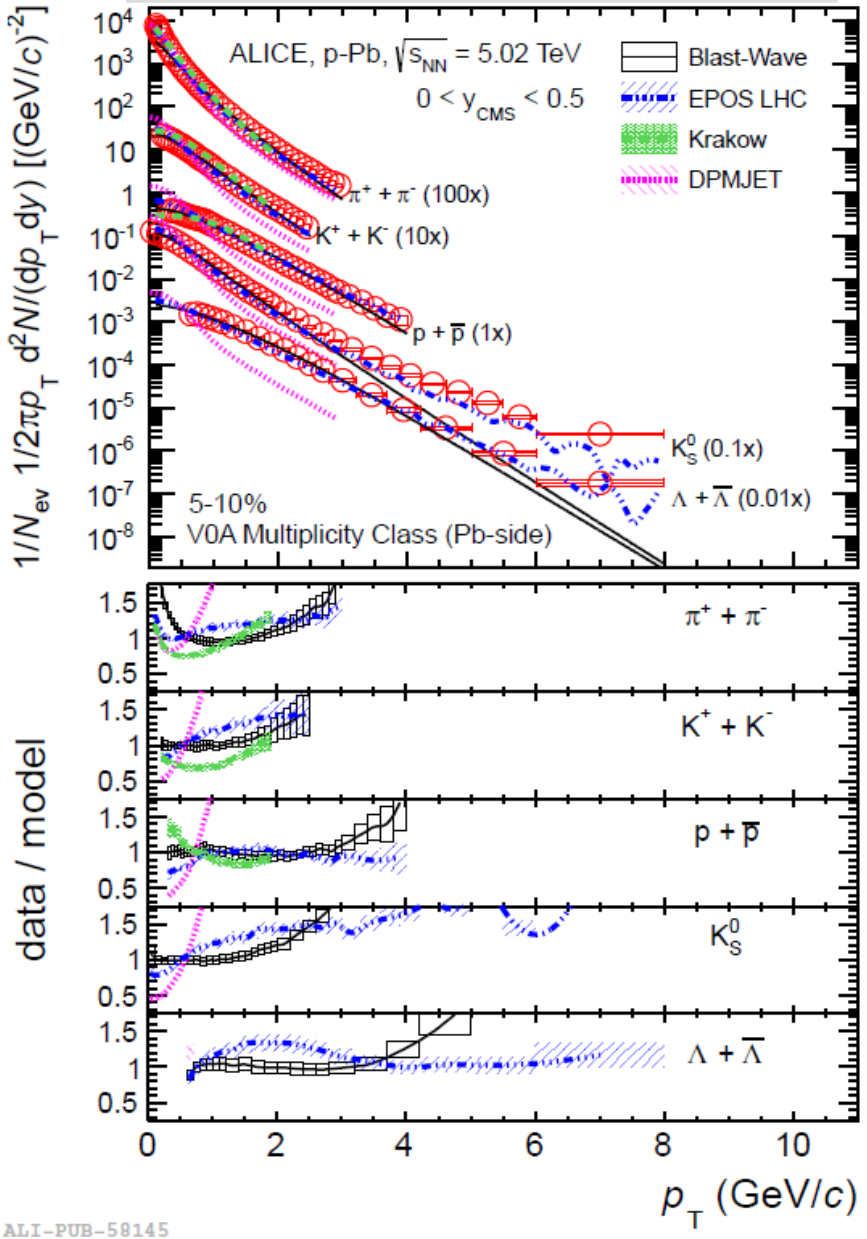
  A. Ortiz *et al.* PRL 111 (2013) 4, 042001
- **pp collisions exhibit flow-like behavior**

Blast wave fits to the spectra

V0A Multiplicity Class: 5-10%



The p_T spectra in high multiplicity pp and p-Pb collisions show a clear evolution with multiplicity
→ this effect is well known from heavy ion collisions

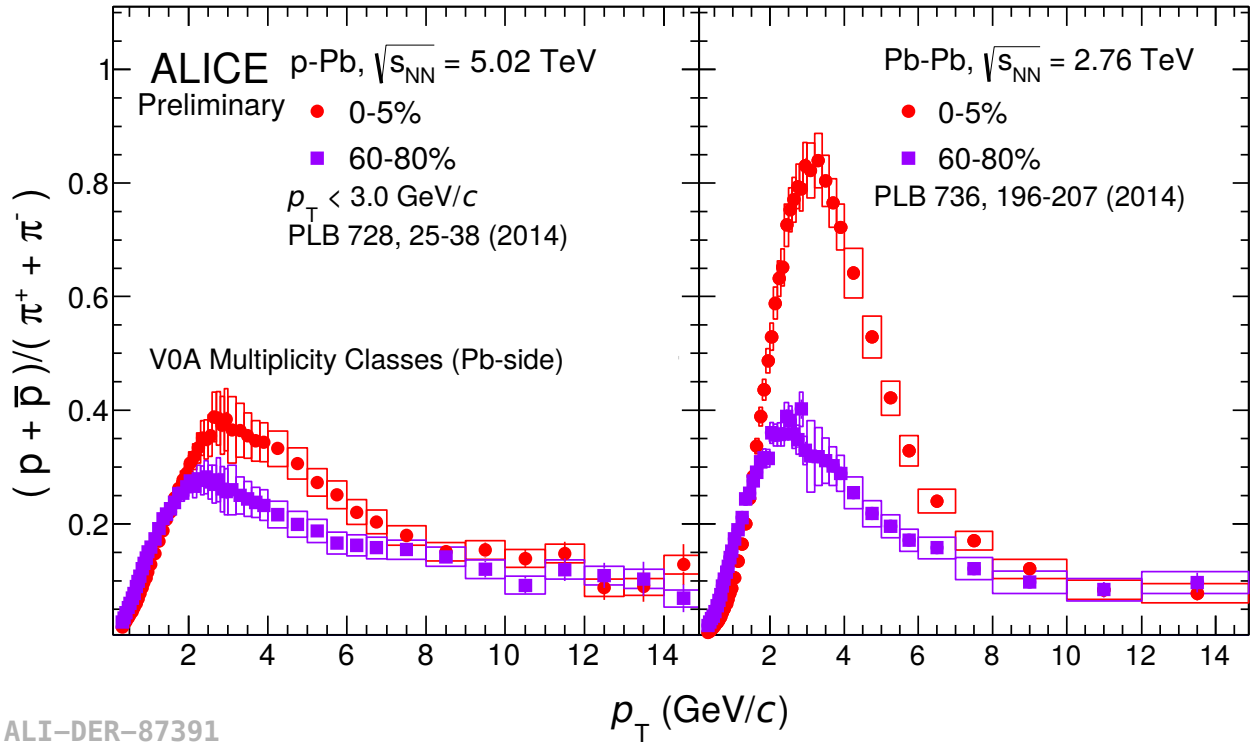
- models, e.g. the Kraków **hydro**dynamic **model**, **reproduce** the **kaon** and **pion spectra** fairly well **below 1 GeV/*c***
- A **deviation for higher p_T** might show the **limit of hydro**dynamical models. The data could indicate the onset of a non-thermal (hard) component, which is not dominated by the flow-boosted thermal component in more peripheral collisions
- **Models** incorporating **final state effects,** such as EPOS, give **good description** of the data

- **Common kinetic freeze-out** describes the spectra in high multiplicity p-Pb collisions
- This feature is **also observed in pp** events simulated with PYTHIA8

ALI-PUB-58145

Multiplicity dependence of kaon/pion and proton/pion particle ratios

- **At intermediate p_T** ($2<p_T<10$ GeV/c), the **proton-to-pion ratio increases with event multiplicity** (and a corresponding depletion at low p_T)
- The behavior of this **increase** is qualitatively **similar to** that observed in **Pb-Pb** collisions
  → its multiplicity dependence for $p_T \leq 1$ GeV/c is a feature of radial flow
- **At high p_T** (>10 GeV/c) the particle ratios in **p-Pb and Pb-Pb** are **consistent**

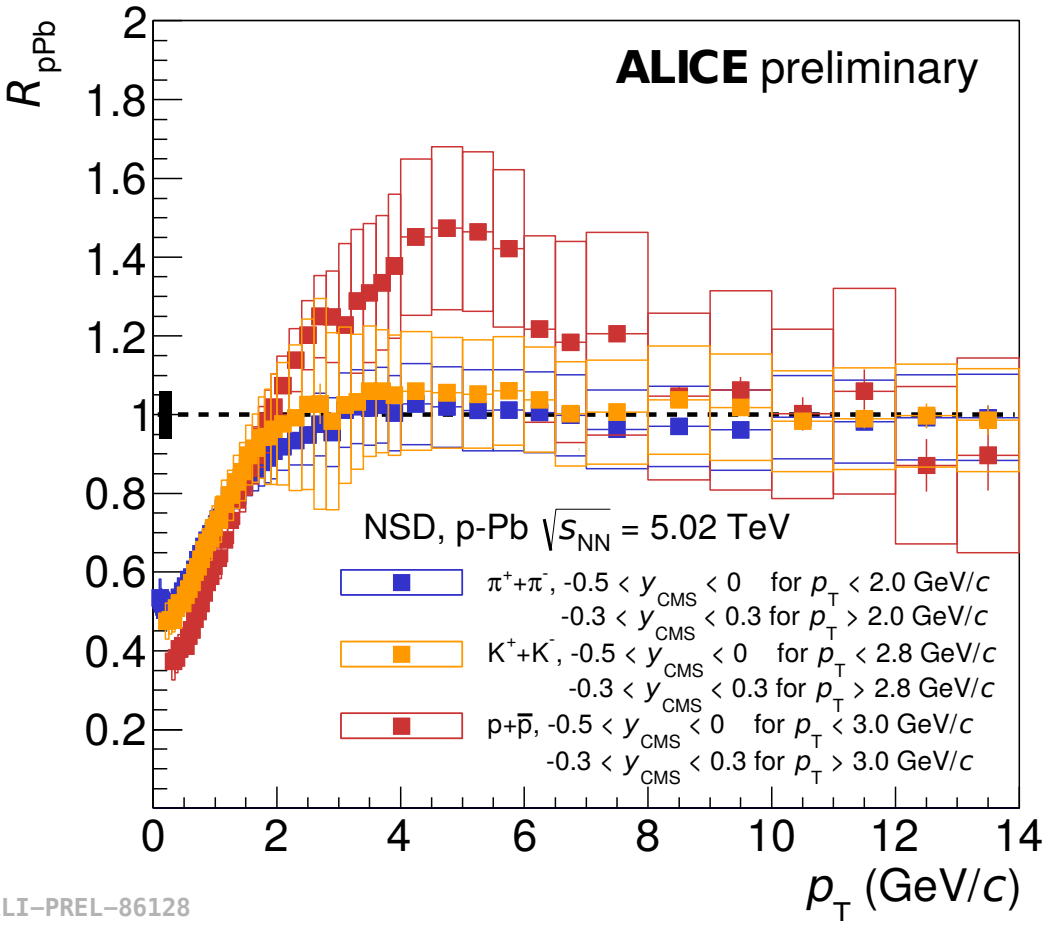


Nuclear modification factor of pi/K/p

$$R_{\mathrm{pPb}} = \frac{\mathrm{d}^2 N_{\mathrm{pPb}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}{\langle T_{\mathrm{pPb}} \rangle \, \mathrm{d}^2 \sigma_{\mathrm{pp}}^{\mathrm{INEL}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}$$

- **Measured for NSD events**
  - Nuclear overlap $\langle T_{\mathrm{pPb}} \rangle$ is not measured yet in mult. classes
- **No pp measurement at 5.02 TeV**: it has to be interpolated between existing measurements

- **At intermediate p_{T}** the **proton R_{pPb}** shows a **Cronin-like enhancement**, while pions and kaons show little or no nuclear modification
- **At higher p_{T}** the pion, kaon and proton R_{pPb} are consistent with **unity**

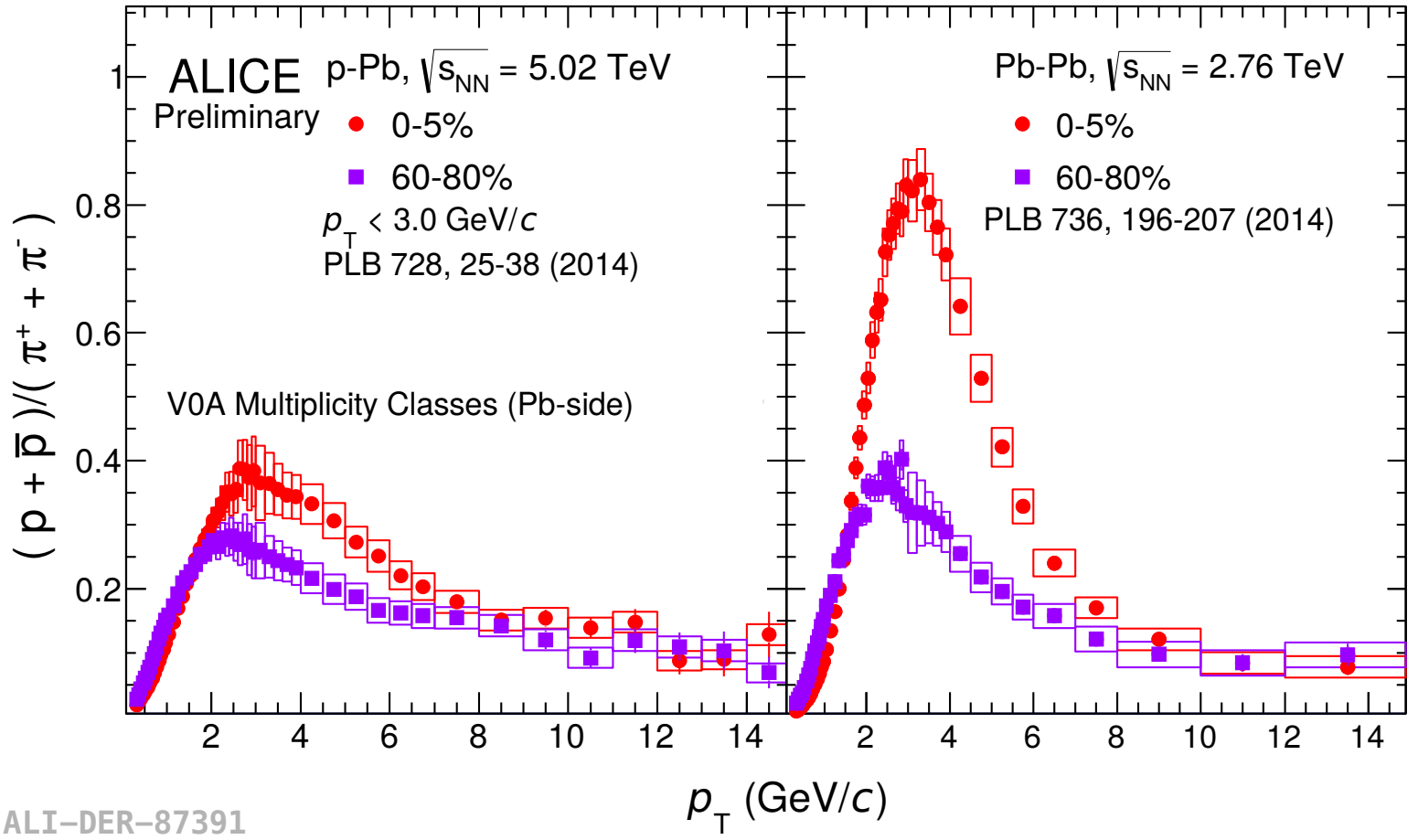


Summary

- **p-Pb and Pb-Pb** collisions have very similar **behavior** in many ways
- p-Pb: p_T spectra show flow-like behavior
- p-Pb: **multiplicity dependence of the proton-to-pion** ratio *vs.* p_T is qualitatively **similar** to the **centrality evolution** of this ratio **in Pb-Pb** collisions
- Cronin-like enhancement observed for protons at intermediate p_T (initial state effects); no nuclear modification at high p_T

Backup

- At intermediate p_T ($2<p_T<10$ GeV/c), the proton-to-pion ratio increases with the event multiplicity.
- The behavior of this increase is qualitatively similar to that observed in Pb-Pb collisions.
- At high p_T (>10 GeV/c) the particle ratios in p-Pb and Pb-Pb are consistent.



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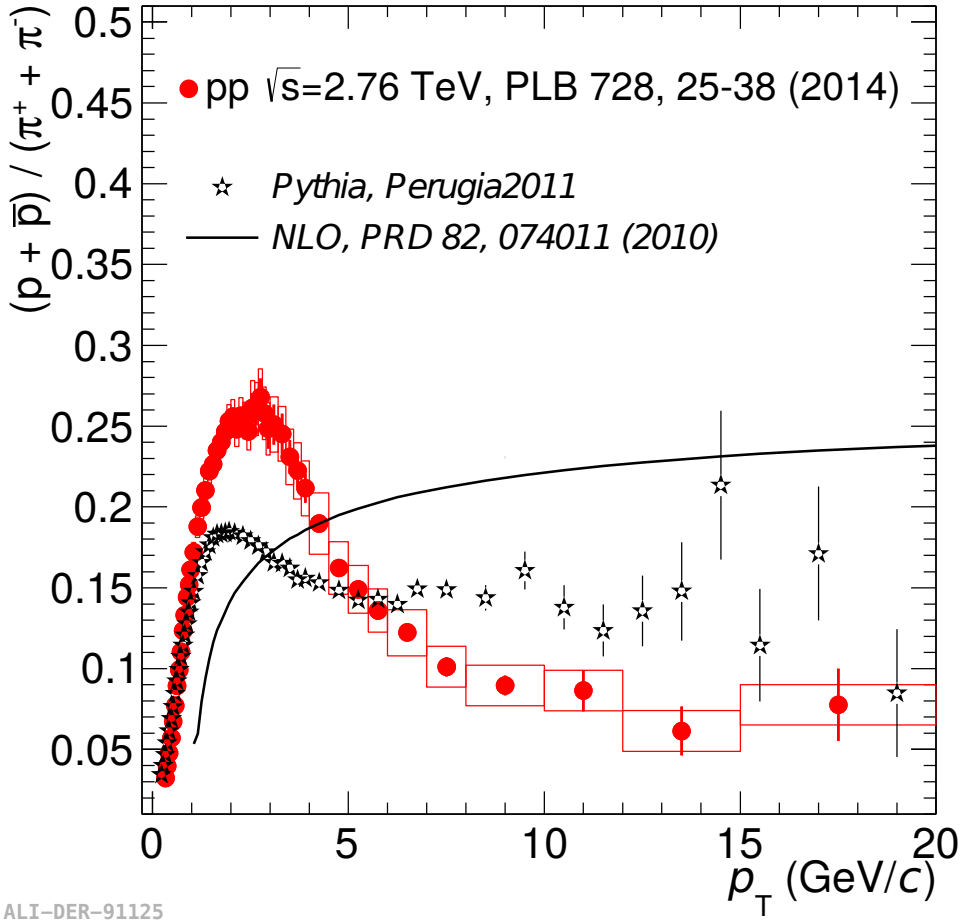

Also in INEL √s = 2.76 TeV pp collisions the "bump" at intermediate p_T is observed.